TEMPERATURE RISE IN ICE CORES DURING A WATER JET CUTTING PROCESS

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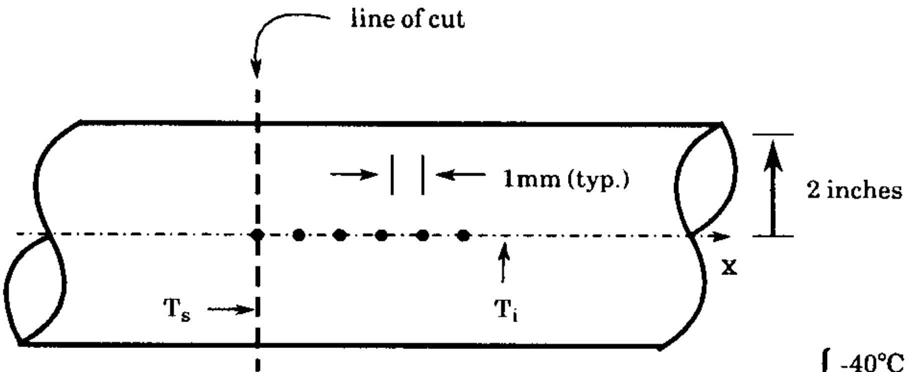
INTRODUCTION

Cutting ice cores by means of high pressure water jets appears to be a better technique than the conventional way of cutting by saw. In this analysis we have attempted to estimate the heating effect of the jet on the core. That is, can the warm water jet heat up the ice core so much that it may cause subsequent structural damage to the core?

For this investigation a 4-inch diameter ice core is considered. The cutting jet diameter is 0.005 inch and its speed is about 1 inch per second. Therefore, at this average speed it can cut through the core in 4 seconds and we have calculated the temperature rise in the ice core for a cutting time of 4 seconds. Two initial temperatures for the ice core are assumed: -40°C (Case - I) and -80°C (Case - II). A water jet temperature of 20°C is used. For determining the temperature rise in the ice core due to its contact at the cutting surface with the water jet, we selected five points; each 1 mm apart as shown in Figure 1. Any of these temperatures and distances can be easily changed and similar calculations repeated.



$T_s = 20°C, \quad T_i = \begin{cases} -40°C \text{ (case - I)} \\ -80°C \text{ (case - II)} \end{cases}$

T_s = Surface Temperature

T_i = Initial Temperature

Figure 1. Temperature determination along the ice core.

HEAT CONDUCTION EQUATION

The cutting surface on the core is assumed to be at the water jet temperature. Points along the core centerline were idealized as positions in a semi-infinite solid with the boundary surface at the cutting plane. The equation for temperature distribution for the semi-infinite medium is obtained from Incropera and Dewitt (1985).

$$T(x,t) = (T_i - T_s)\, erf\left(\frac{x}{2\sqrt{\alpha t}}\right) + T_s \qquad (1)$$

Where T(x,t) is the variable temperature at any distance, x, from the cutting surface and at any time, t. Temperature T_i is the initial temperature of the ice core and T_s is the temperature at the surface where the jet touches the core. The thermal diffusivity of ice, α, is understood to be 1.33×10^{-6} m^2/s at -55° C (Hutter, 1983).

Two sets of calculations were performed using equation (1); Case - I for the initial ice temperature, T_i = -40°C = 233K and Case - II for T_i = -80°C = 193K. The calculated results are tabulated for x = 1,2 . . . . . . 5 mm and t = 1,2 . . . . . . 4 seconds.

EXPERIMENTAL RESULTS

As a check, a core was instrumented with a thermistor 3 mm from the cut, located at the core center. Resistance was measured and noted at intervals of 2 seconds for 16 seconds.

Figure 2 shows a plot of temperature rise versus time, illustrating that there is no noticeable deviation from the steady rise after cutting. This temperature rise resulted from using -40°C ice in a room at 20°C and 100% humidity. Condensation on the core was immediate and produced thermal gradients on the outside surface of the core, sufficient to cause fracture. Resulting temperature rise in the core was still less than predicted by the model, suggesting the surface temperature of the core never reached 20°C as assumed.

DISCUSSION OF RESULTS AND CONCLUSION

Temperatures summarized in Tables 1 and 2 were plotted to easily visualize the heating effect. Figure 3 displays the temperature variation in the ice core during the four seconds of cutting. The ice is initially maintained at T_i = -40°C = 233K. It shows that after the *first three millimeters*, there is negligible rise in the temperature in the core. Similar observations are made for a cooler ice core (Figure 4) where initially the ice is at -80°C. In this case, the *first three and a half millimeters* are affected by the heating process of the jet. Beyond that distance the temperature rise is negligible.

Therefore, it appears that water jet cutting is a viable technique for ice cores if the heating effect on the first few millimeters can be tolerated. The heat affected zone will be limited to about 3 mm. It may go up slightly and that can be easily determined by repeating the calculations, using equation (1) on larger diameter cores, for low jet cutting speed and for higher water temperature.

REFERENCES

Hutter, Kolumban. 1983. *Theoretical Glaciology*. D. Reidel Publishing Company, Dordrecht, Holland. p. 163.

Incropera, F. P. and D. P. Dewitt. 1985. *Fundamentals of Heat and Mass Transfer*. Second Edition, John Wiley & Sons, New York. pp. 202-203.

RESULTS

Table 1. Case - I T_i = -40°C = 233K

t = 1 seconds

x(mm)	T(x,t) (K)
1	265.02
2	246.11
3	237.2
4	233.84
5	233.12

t = 2 seconds

x(mm)	T(x,t) (K)
1	273.29
2	256.2
3	245.18
4	238.08
5	234.8

t = 3 seconds

x(mm)	T(x,t) (K)
1	275.78
2	262.7
3	249.95
4	242.43
5	237.76

t = 4 seconds

x(mm)	T(x,t) (K)
1	277.05
2	263.92
3	251.20
4	244.59
5	239.05

Table 2. Case - II T_i = -80°C = 193K

t = 1 seconds

x(mm)	T(x,t) (K)
1	248.22
2	215.39
3	200.00
4	194.4
5	193.2

t = 2 seconds

x(mm)	T(x,t) (K)
1	260.13
2	231.68
3	213.3
4	201.76
5	196.3

t = 3 seconds

x(mm)	T(x,t) (K)
1	264.61
2	242.53
3	221.8
4	209.03
5	200.80

t = 4 seconds

x(mm)	T(x,t) (K)
1	270.3
2	248.3
3	232.3
4	215.69
5	205.96

$T = {}^{1}/_{A} + (B \ln R) + c\,(\ln R)^3$

Where
A = 0.133446 E -02
B = 0.258465 E -03
C = 0.149798 E -06
D = Resistance (ohms)

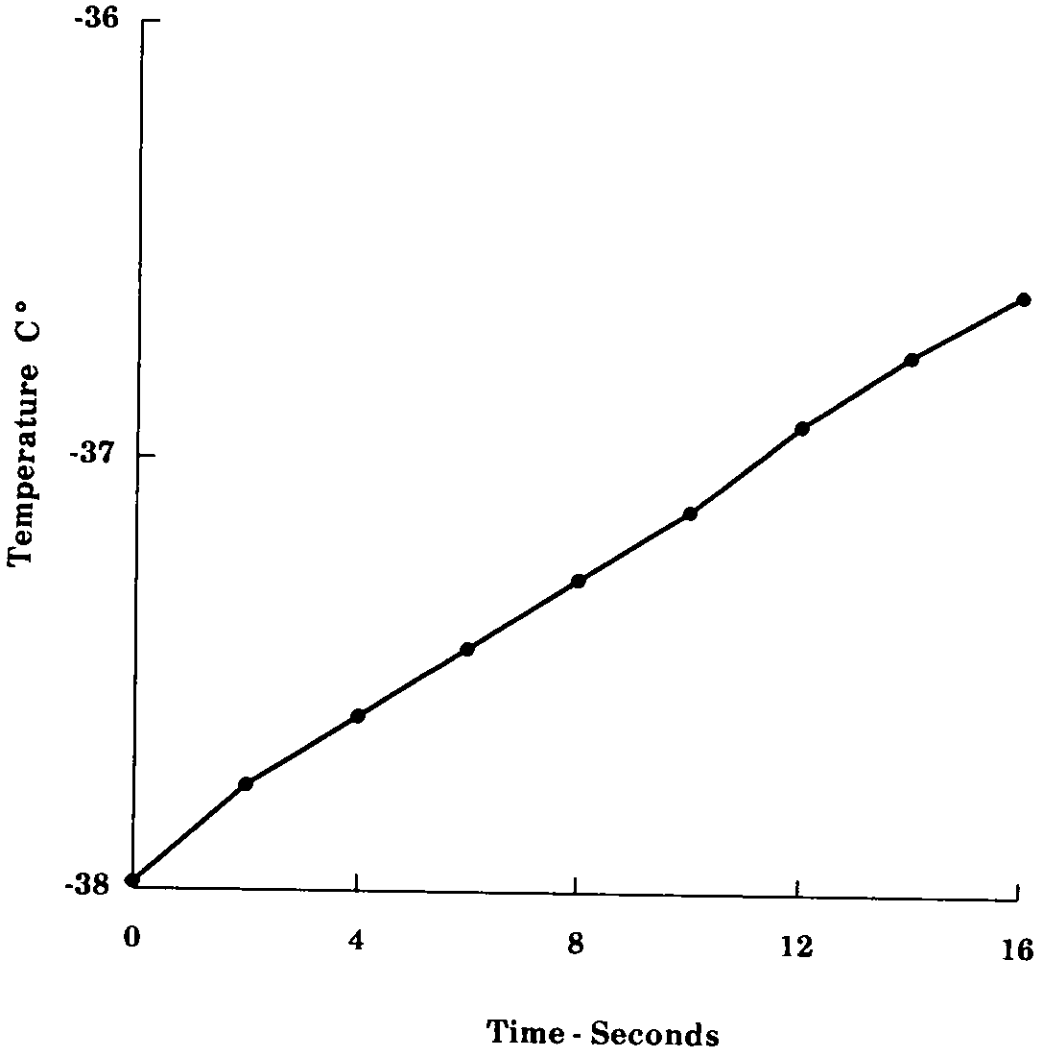


Figure 2. Temperature measured at the ice core center 3mm from the cut.

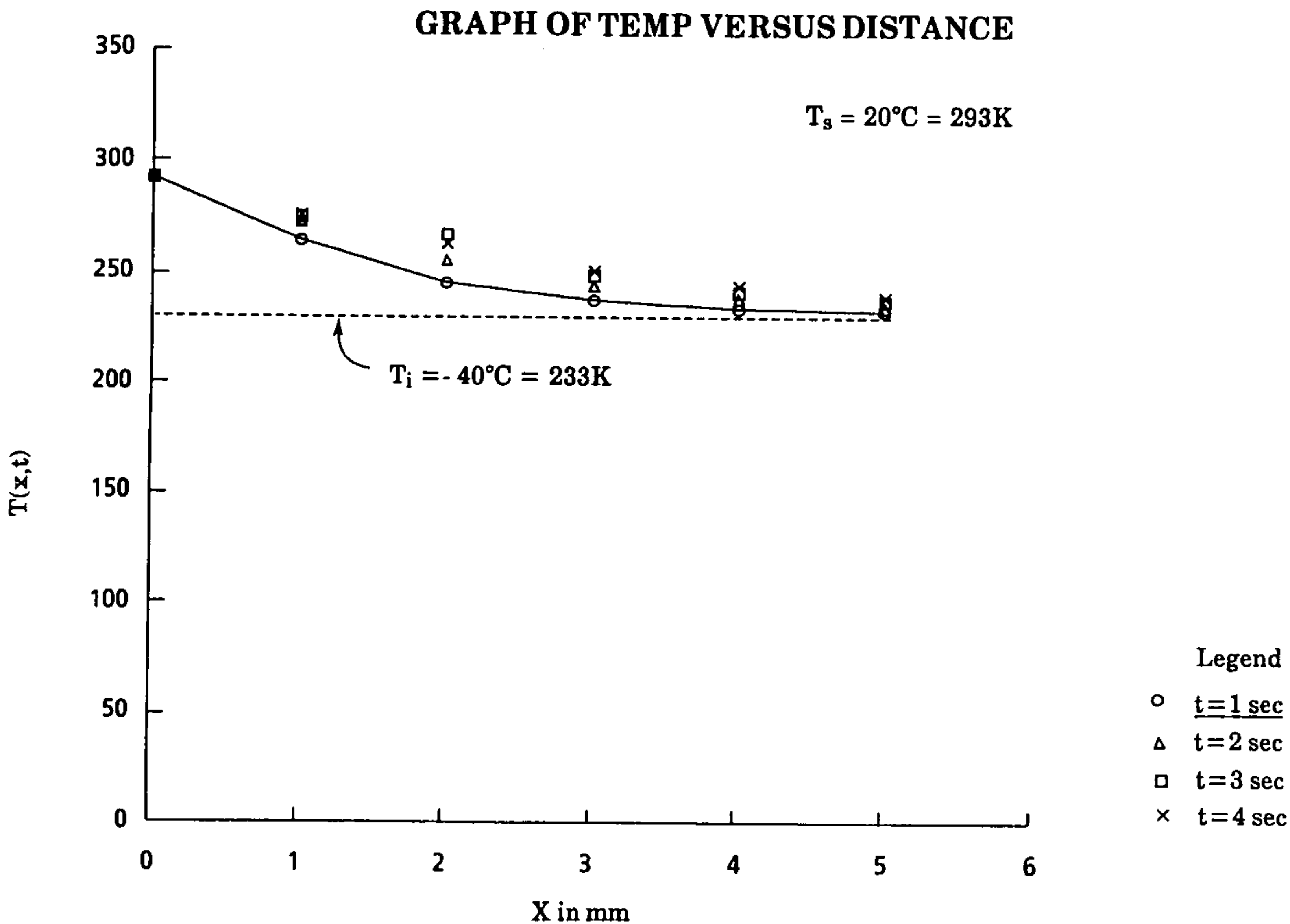


Figure 3. Temperature distribution in the ice core, initially at 233K, after cutting.

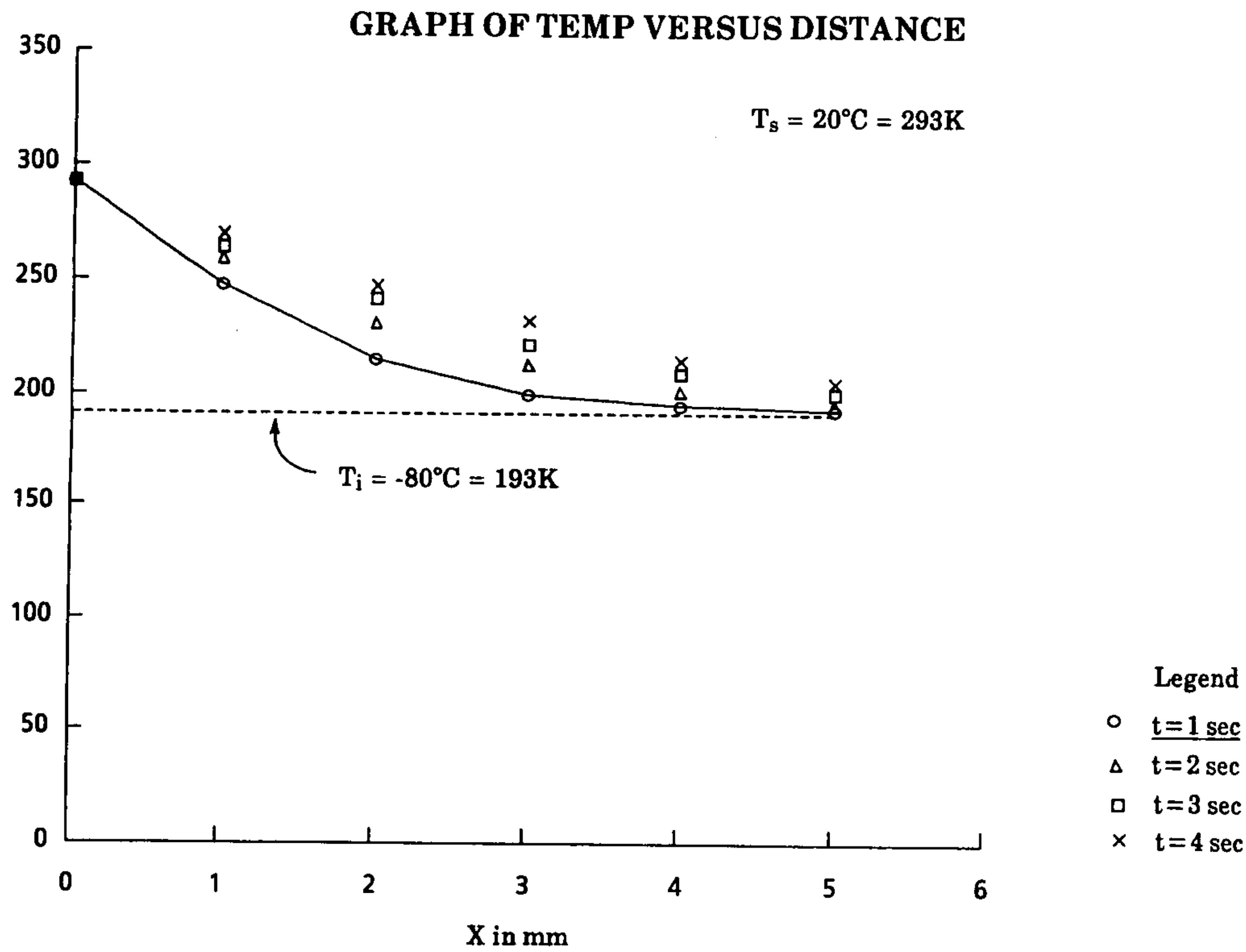


Figure 4. Temperature distribution in the ice core, initially at 193K, after cutting.